Estimating JPEG2000 Compression for Image Forensics Using the Benford's Law

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ABSTRACT

With the tremendous growth and usage of digital images nowadays, the integrity and authenticity of digital content is becoming increasingly important, and a growing concern to many government and commercial sectors. Image Forensics, based on a passive statistical analysis of the image data only, is an alternative approach to the active embedding of data associated with Digital Watermarking.

Benford's Law was first introduced to analyse the probability distribution of the 1st digit (1-9) numbers of natural data, and has since been applied to Accounting Forensics for detecting fraudulent income tax returns [9]. More recently, Benford's Law has been further applied to image processing and image forensics. For example, Fu et al. [5] proposed a Generalised Benford's Law technique for estimating the Quality Factor (QF) of JPEG compressed images. In our previous work, we proposed a framework incorporating the Generalised Benford's Law to accurately detect unknown JPEG compression rates of watermarked images in semi-fragile watermarking schemes. JPEG2000 (a relatively new image compression standard) offers higher compression rates and better image quality as compared to JPEG compression. In this paper, we propose the novel use of Benford's Law for estimating JPEG2000 compression for image forensics applications. By analysing the DWT coefficients and JPEG2000 compression on 1338 test images, the initial results indicate that the 1st digit probability of DWT coefficients follow the Benford's Law. The unknown JPEG2000 compression rates of the image can also be derived, and proved with the help of a divergence factor, which shows the deviation between the probabilities and Benford's Law.

Based on 1338 test images, the mean divergence for DWT coefficients is approximately 0.0016, which is lower than DCT coefficients at 0.0034. However, the mean divergence for JPEG2000 images compression rate at 0.1 is 0.0108, which is much higher than uncompressed DWT coefficients. This result clearly indicates a presence of compression in the image. Moreover, we compare the results of 1st digit probability and divergence among JPEG2000 compression rates at 0.1, 0.3, 0.5 and 0.9. The initial results show that the expected difference among them could be used for further analysis to estimate the unknown JPEG2000 compression rates.

Keywords: Image Forensics, JPEG2000, Benford's Law, DWT, DCT, JASPER

1. INTRODUCTION

As digital imaging devices such as digital cameras, camcorders and scanners have become very popular and widely available in the market place; the use of digital images has grown considerably in our daily life. This, coupled with the ease-of-use and effectiveness of advanced image manipulation software, has made altered images ubiquitous in the digital world, raising a concern regarding the integrity of images. In order to restore trust in an image, the field of image forensics has been developed to analyse images based solely on the image data itself. The primary focus of image forensics is to detect and authenticate any kind of manipulation in a digital image. Image forensics can be viewed as an alternate approach to digital watermarking, where secret information (watermarks) are embedded into an image to protect its authenticity. The advantage of Image forensics, however, is that it works only with the data in hand, and does not require embedding any additional information. As described in [1, 2] image forensics also isolates anomalies that might exist due to non-malicious processing (such as a change in file format) or intentional, malicious modifications

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(such as cloning or creating composites), as well as identifying the difference between natural and unnatural images [3]. A natural image possesses its original characteristics, such as shape, contrast and size. On the other hand, this image becomes unnatural if any of these characteristics are changed.

Fridrich et al [2] classified image forensic techniques according to six different categories: source classification; device identification; images linking to source device [4]; processing history recovery; integrity detection; and anomaly investigation. Processing history recovery relates to the part recovery of the processing chain associated with an image [2]. This area of image forensics focuses on detecting non-malicious alterations in an image such as lossy compression (JPEG, JPEG2000), resizing, and colour/contrast adjustments. Fu *et al.* [5] proposed an image forensic technique to detect the Quality Factor (QF) of unknown JPEG compressed images. They found that DCT coefficients of an image obey the Benford's Law distribution closely, and that the 1st digit probability distributions do not follow the Generalized Benford's Law if the image has been compressed twice with different QFs. Hence, the actual QF can be accurately estimated by analysing its JPEG coefficients according to the Generalised Benford's Law [6-8]. Benford's Law is a statistical model of probabilities [8], used originally in accounting forensics [9] to detect financial frauds. We also adapted this approach to determine adaptive thresholds that could improve the authentication accuracy in semi-fragile watermarking [10].

Zhang *et al*. [11] proposed a double compression detection technique for JPEG2000 compressed images. Double compression occurs when an image is saved twice in same format with different or similar compression. In their scheme, they applied the Discrete Wavelet Transform (DWT) to a JPEG2000 compressed image, to extract the High/Low and Low/High sub-bands of the DWT coefficients. A histogram was then formed by applying the Fast Fourier Transform (FFT) to these extracted coefficients. By analysing the sharp peaks and valleys of this histogram, this test image could be classified according to whether or not it has been subjected to double JPEG2000 compression. There currently exists no literature regarding the analysis of single JPEG2000 compression for image forensics. In this paper, we propose the novel use of Benford's Law for single JPEG2000 compressed images. We will analyse the DWT coefficients of uncompressed and JPEG2000 compressed images based on the Benford's Law. A comparative evaluation of compression rates will also be investigated. In contrast with Fu *et al.* [5], we analyse the DWT coefficients instead of DCT coefficients before the quantisation step. This is due to the fact that the quantization has no effect in the compression process in a JPEG2000 compression coding system, which will be explained in the next section [12].

The remainder of the paper is organised as follows. Section 2 describes the background of JPEG2000, DWT and the Benford's Law. In this section, a brief description of the JPEG2000 core coding system is given, along with an explanation of DWT, and the advantages of using DWT over DCT in JPEG2000 compression. It also provides a brief discussion of why Benford's Law is a useful tool for image forensics. Section 3 discusses the results obtained using the proposed method of utilising Benford's Law to analyse DWT coefficients of both uncompressed and JPEG2000 compressed images. Finally, Section 4 presents the conclusions and future work.

2. BACKGROUND

2.1 JPEG2000 Compression

In the literature, there are two major classes of image compressions: lossy and lossless [13]. Lossy image compression produces an image with acceptable visual quality but with a significantly smaller file size. One of the most popular lossy compression techniques is the JPEG (Joint Photographic Experts Group) format, which was implemented based on the block Discrete Cosine Transform (DCT) [13]. In JPEG, the compression is achieved by applying the quantization and coding process to the DCT coefficients of an image. The purpose of the quantization step is to remove redundancies of the image data with a Quality Factor (QF), that represents different compression rates. However, the JPEG compressed image can possess blocking artefacts at low quality factors, due to the use of the block DCT. To overcome this, a newer version of JPEG was introduced, JPEG2000 (file extensions jp2 or j2k) [14, 15]. JPEG2000, based on the Discrete Wavelet Transform (DWT) [12], has better quality, with no blocking artefacts; it is more complex in implementation than JPEG. A block diagram of the JPEG2000 core coding system is shown in Figure 1 [15].

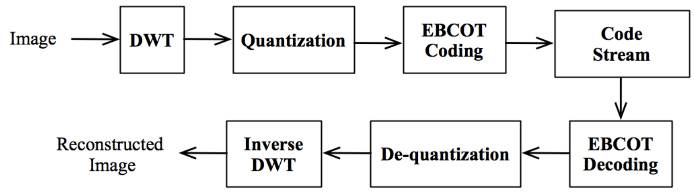

Figure 1: Block diagram of core coding system of JPEG2000 [15]

As shown in Figure 1, there are three important components: DWT; Quantization; and Embedded Block Coding with Optimized Truncation (EBCOT). Firstly, DWT is applied to the image, followed by quantization. In contrast to JPEG, the quantization is performed by dividing each coefficient with the step size (which does not affect the compression rate in JPEG20000). EBCOT coding is the next step in the process, where the quantized coefficients are formed into bit-planes starting from the Most Significant Bit (MSB) to Least Significant Bit (LSB). These bit-planes then undergo three coding passes: the significance propagation pass; the amplitude refinement pass; and the cleanup pass. Then, the coded stream is achieved by arranging coded bits into quality layers according to desired compression rate. Finally, the code stream is used to reconstruct the JPEG2000 compressed image [12, 14, 15].

In this paper, we used JASPER [16], an open source implementation of JPEG2000 in C, with MATLAB for our experiments. In JASPER, compression parameters are used to apply different compression rates between 0.01 and 1, which represent the percentage size of the original image. A total of 1338 test images, from UCID [17] database are used for our experiment and analysis.

2.2 DWT for JPEG2000

As mentioned above, DWT is used in JPEG2000 for mapping spatial pixels of an image into coefficients in the frequency domain. In contrast with DCT, which divides the image into 8 by 8 blocks, the DWT is applied to the entire image, yielding a much better energy compaction while reducing discontinuities at the same time [12]. As shown in Figure 2, DWT decomposes an image into power of 2 resolution levels by applying a collection of low-pass and high-pass filters onto the image in vertical and horizontal directions. Each resolution level consists of four sub-bands, which are LL, HL, LH, and HH. In JPEG2000, the resolution levels are often between 3 to 8. JPEG2000 compression can be both lossy and lossless, depending upon the type of filter applied in DWT. For instance, Le Gall 5/3 filter is used for lossless compression, and Daubechies 9/7 filter is used for lossy compression [6, 7, 8]. In this paper we will analyse the lossy JPEG2000 images using Benford's Law in comparison with DCT in [5].

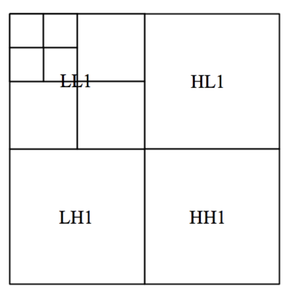

Figure 2: DWT decomposition

2.3 Benford's Law

The Benford's Law, was introduced by Frank Benford in 1938 [7] and was later developed by Hill [8] for analysis of the probability distribution of the first digit (1-9) numbers obtained from natural data in statistics. A typical probability distribution of Benford's Law is shown in Figure 3. By using Benford's Law, the 1st digit of natural numbers (1-9) can be classified in a specific way, that is smaller digit occurs more often than larger digit. Hill explained the law in terms of statistics, concluding that the nature of probabilities of first digits from 1 to 9 is logarithmic [8]. The distribution for Benford's Law can be expressed by Equation 1.

$$p(x) = \log_{10}\left(1 + \frac{1}{x}\right), \qquad x = 1, 2, \ldots 9 \tag{1}$$

where x is the first digits of the number and $p(x)$ is the probability distribution of x.

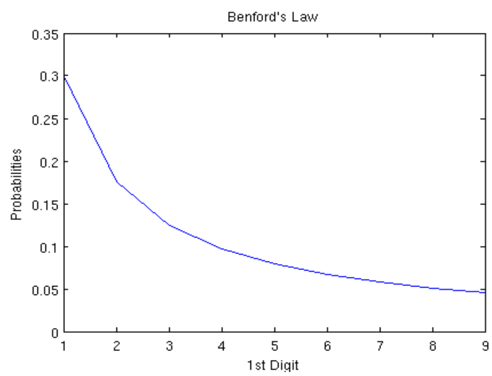

Figure 3: Probability distribution of Benford's Law

3. METHOD AND RESULTS

3.1 DWT coefficients and Benford's Law

We analyse the DWT coefficients of the uncompressed images to investigate if these coefficients follow the Benford's Law, and the result will also be a benchmark for the next experiment on JPEG2000 images. The DCT coefficients are non-uniformly distributed; therefore, the Benford's Law can be successfully applied to the first digits of DCT coefficients [5]. The DWT coefficients have similar property of the DCT, which is illustrated in the following figures. Figure 4 illustrated the image 'Cameraman' and its associated probabilities of DCT and DWT coefficients as compared with the Benford's Law as shown in Figure 5. The 'Lena' image is shown in Figure 6 and the associated probabilities of DCT and DWT are shown in Figure 7.

Figure 4: image ‘Cameraman’

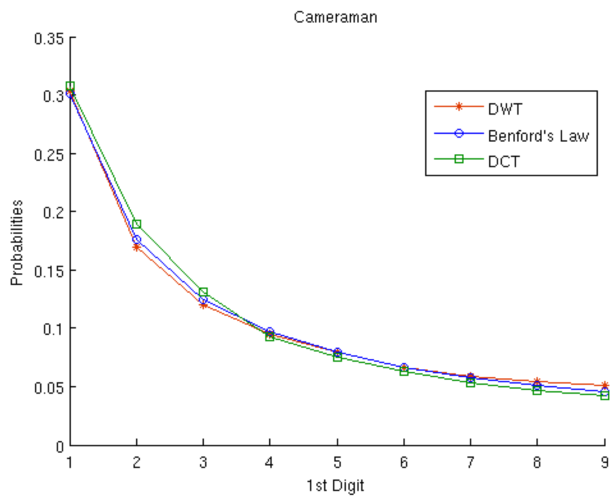

Figure 5: 1^{st} digits probabilities of ‘Cameraman’

Figure 6: image ‘Lena’

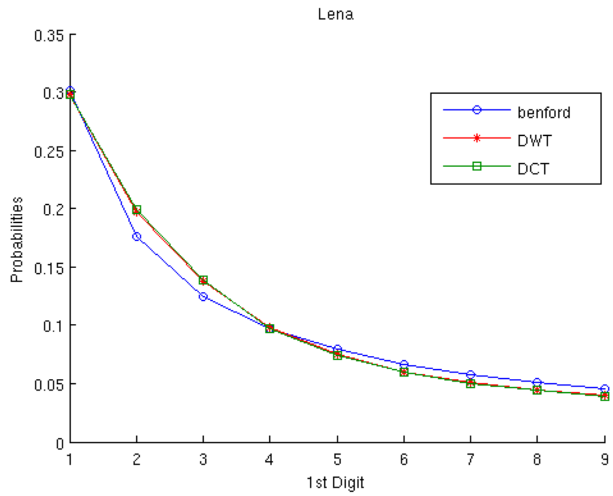

Figure 7: 1st digits probabilities of 'Lena'

The results are obtained by applying level 3 DWT of the image, and non-overlapped 8 by 8 block of DCT to uncompressed images, and then calculate the 1st digits probabilities of their corresponded coefficients. Figures 5 and 7 show that the DWT coefficients for the two test images are following the trend of the Benford's Law. Furthermore, for the lower complexity image 'Cameraman' in Figure 5, the trend of DWT coefficients is closer to the Benford's Law than DCT coefficients. One the other hand, for the higher complexity image 'Lena' in Figure 7, both DWT and DCT have similar trends and follow the Benford's Law. Hence, the results implied that the 1st digits probabilities for DWT coefficients perform better in lower complexity images.

In order to substantiate the results, we conduct the experiment of evaluating the 1st digits probabilities for 1338 uncompressed grayscale images from the Uncompressed Image Database (UCID) [17]. Figure 8 illustrates the comparison between the probability distribution of Benford's Law, and the mean distribution of 1st digit of uncompressed DWT coefficients of 1338 images. The results also show that the distribution of the 1st digits of the uncompressed DWT coefficients obeys the Benford's Law closely. In order to evaluate how much deviation of the mean distribution to Benford's Law, we calculate the average divergence [18], as given in Equation 2.

$$\chi^2 = \sum_{i=1}^{9} \frac{(p_i' - p_i)^2}{p_i} \qquad \text{for i=1...9} \qquad (2)$$

where p_i' is the actual 1st digits probability of the DWT coefficients and p_i is the 1st digits probability from Benford's Law in Equation (1). Based on 1338 test images, the average divergence of mean probability is 0.0016, which is even lower than the divergence of DCT coefficients at 0.0034, observed by Fu *et al.* [5]. Therefore, the results indicate a good fitting between the probability distribution of Benford's Law and the uncompressed DWT images.

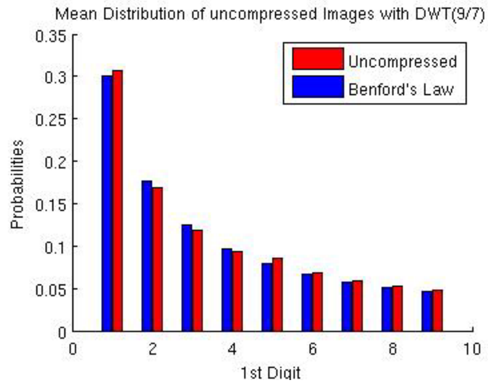

Figure 8: 1st digits probabilities of uncompressed DWT coefficients

3.2 Benford's Law and Compressed JPEG2000 Images

From the results analysed from the last section, we conclude that the uncompressed DWT coefficients follow the Benford’s Law. We will further analyse the compressed DWT coefficients from JPEG2000 images. The schematic diagram of the conducted experiment is shown in Figure 9. The grayscale original image is first compressed and saved into JPEG2000 format (.jp2) via the JPEG2000 compression software, JASPER. Next, the compressed image is then saved to a different format (.bmp, .tiff). The saved image can be passed to the receiver since the compression rate is unknown. Afterwards, the receiver can read the BMP format image and apply DWT to it. Finally, the receiver calculates the 1st digits Benford’s Law of this test image to detect unknown compression rate. In JASPER, compression parameters are used to apply different compression rates between 0.01 and 1, which represent the percentage size of the original image. The bits-per-pixel parameter is set at 8 bits in our experiment.

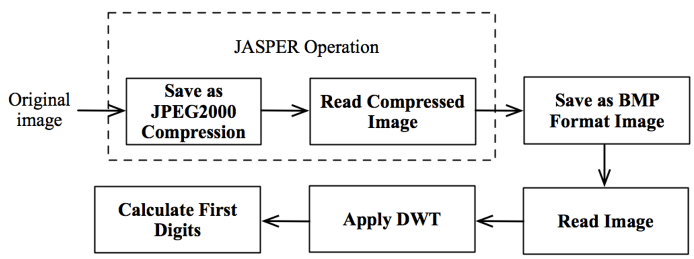

Figure 9: Block diagram of experiment conducted

Based on 1338 images, Figures 10 to 13 show the 1st digits probabilities of compressed DWT coefficients (extract from JPEG2000 compressed image) with different compression rates, 0.1, 0.3, 0.5 and 0.9, which are compared with the Benford’s Law, respectively. As we can see from the figures, most of the 1st digital probabilities obey the Benford’s Law under different compression rates. However, the trends of compression rates at 0.9 and 0.5 are closer to the Benford’s Law than 0.3 and 0.1, respectively. For the divergence evaluation, the mean divergence for JPEG2000 images compression rate at 0.1 is 0.0108, which is approximately 10 times higher than the compression rate at 0.9. These variations in the divergences could be used to detect the compressions rate of JPEG2000 images. Hence, for JPEG2000 images, we can conclude that the 1st digits probabilities of compressed DWT coefficients follow the Benford’s Law based on the different compression rates. This property could be further explored to accurately estimate unknown JPEG2000 compression in image forensics.

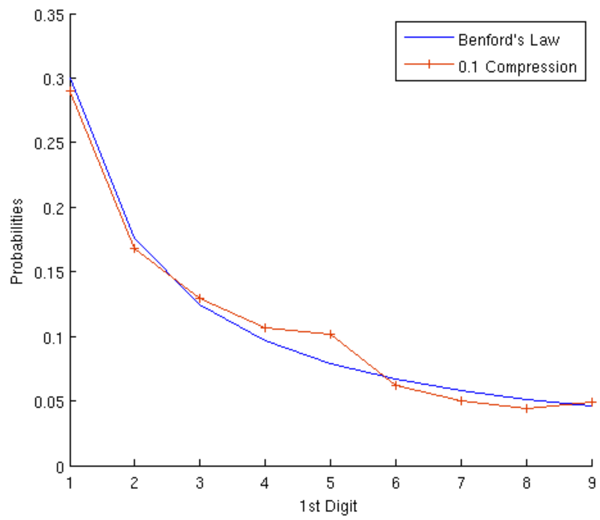

Figure 10: 1st digits probabilities of JPEG2000 compression rate at 0.1

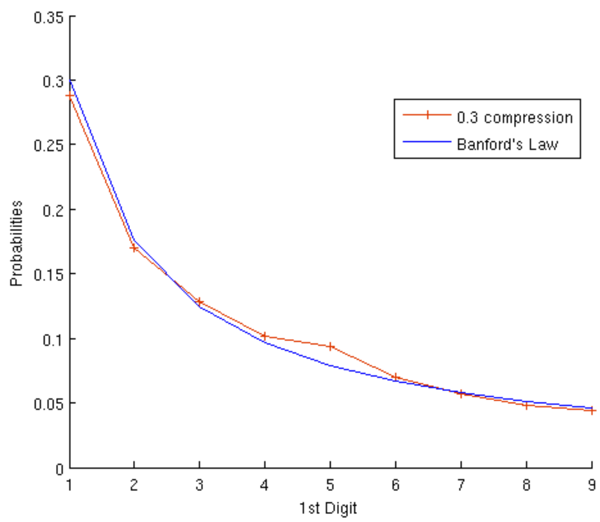

Figure 11: 1st digits probabilities of JPEG2000 compression rate at 0.3

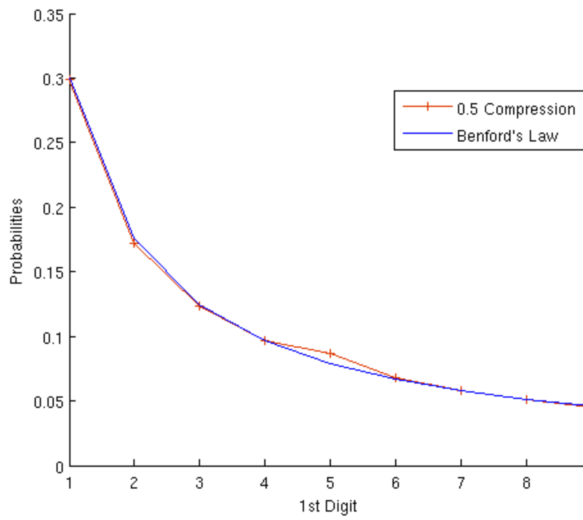

Figure 12: 1st digits probabilities of JPEG2000 compression rate at 0.5

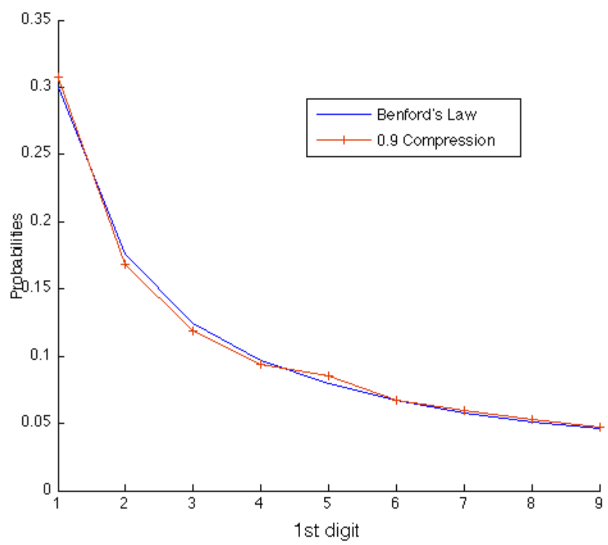

Figure 13: 1st digits probabilities of JPEG2000 compression rate at 0.9

4. CONCLUSION & FUTURE WORK

In this paper, we proposed a scheme to analyse DWT coefficients and JPEG2000 compressed images using the Benford's Law for image forensic applications. The uncompressed DWT coefficients were found to obey the Benford's Law based on 1338 test images. By using a divergence factor, the mean divergence for DWT coefficients was estimated to be 0.0016, which was lower than the DCT coefficients at 0.0034. These deviations indicated that the DWT coefficients followed the Benford's Law much closer than the DCT coefficients. In our second experiment, we analysed the compressed DWT coefficients with different compression rates for JPEG2000 images. The results indicated that the compressed DWT coefficients still obeyed the Benford's Law with some slight difference between them. For example, the mean divergence for JPEG2000 compression rate at 0.1 was 0.0108, which was much higher than uncompressed

DWT coefficients. Hence, from these initial results, we can estimate a presence of JPEG2000 compression and could further analyse to estimate the unknown JPEG2000 compression rates in the image.

For future work, we plan to improve our scheme to accurately estimate unknown compression rates for watermarked images. The coded stream of JPEG2000 can be analysed to further improve the accuracy of detecting unknown JPEG2000 compression rates, as well as using the proposed method to accurately estimate double compression in JPEG2000 images.

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